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BLASTING TO LESSEN BOWLDERS IN HARD-ORE STOPES

BY

E. D. GARDNER AND S. P. HOWELL

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BLASTING TO LESSEN BOWLDERS IN HARD-ORE STOPES

By E. D. Gardner and S. P. Howell

INTRODUCTION

In many western mines the ore is very hard and present methods of drilling and blasting often break it down in large bowlders which must be plugged and blasted or broken by hand.

Breaking up these large fragments is a hazard to the miners, as flying particles of ore from hammering or sledging may injure the eyes or cause cuts and bruises. With large bowlders there is also the hazard of drilling into missed charges.

Besides the risk of injury and the added cost in breaking them, these large fragments in stopes increase the cost of shoveling the ore and often prevent adoption of a more economical stoping method. Were it not for the bowlders many deposits of hard ore could be mined by a method that would permit efficient handling of the broken material by mechanical devices, with a consequent saving in labor. Even if no shoveling is required in the stopes, as at two hard-ore mines in California which are mined by the shrinkage system, the formation of bowlders is a serious disadvantage. After each cut in the stopes at these two mines all visible large fragments are plugged and blasted at the top, but enough bowlders are covered up in blasting to block the chutes repeatedly and increase decidedly the cost of mining.

The Bureau of Mines, in cooperation with the mining companies of the Southwest, is making investigations to ascertain the safest and most economical explosives to be used in metal mines and to determine the best methods of blasting under various conditions. Different phases of the main problems are being taken up at mines where the solution of a problem is of particular advantage to the mine as well as of value to the industry as a whole.

The investigations recorded in this paper were undertaken at the mine of the Calumet & Arizona Mining Co. at Bisbee, Ariz., and at the mine of the United Verde Copper Co. at Jerome, Ariz., at the suggestion of officials of these companies, to ascertain the

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most efficient grade of explosive to use and to develop a method of blasting by which the ore in the hard stopes could be broken from the back in smaller fragments.

In this work the methods of mining and drilling were considered fixed and the investigators have sought a solution of the bowlder problem by the use of improved blasting practices and a better selection of explosives.

ACKNOWLEDGMENTS

The officials of the Calumet & Arizona Mining Co. and the United Verde Copper Co. cordially aided the investigation and ordered special grades of explosives for the work. The following persons gave helpful suggestions and made all arrangements for the test rounds that were blasted: E. E. Whiteley, general superintendent, D. M. Rait, assistant superintendent, and Fred Santher, mine foreman, of the Calumet & Arizona Mining Co.; and H. De Witt Smith, general superintendent, W. V. De Camp, mine superintendent, and Harry Wright, efficiency engineer, of the United Verde Copper Co.

Samples of the explosives used were tested at the explosives experiment station of the Bureau of Mines at Bruceton, Pa., under the direction of J. E. Crawshaw, explosives engineer.

MINES WHERE TESTS WERE MADE

DESCRIPTION OF ORE BODIES

The Calumet & Arizona mine is situated at Lowell, Ariz., in the Warren, or Bisbee, mining district. The lenticular ore bodies occur in a country rock of limestone. The ore consists of chalcocite, chalcopyrite, and bornite in a gangue of pyrite and altered limestone. Most of the ore bodies are soft, because of the admixture of limestone, and require a relatively small amount of explosives to mine. In several of the stopes, however, the ore consists of massive pyrite containing copper minerals and is very hard to break.

The United Verde mine is situated at Jerome, Ariz., in the Verde mining district. Most of the ore is in an immense body of massive pyrite, which extends from near the surface to below the 2,400 level, the deepest level developed. In many of the stopes the ore is extremely hard and breaks in large fragments.

MINING PRACTICE

In the hard-ore stopes of the Calumet & Arizona mine the ore is mined by the inclined cut-and-fill method. An 8-foot cut of ore is

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taken up at an angle of about 40°. The broken ore is raked or shoveled into chutes at the bottom of the stope. Ten-inch grizzlies are used on top of the chutes. The smaller bowlders are broken with hammers and the others are drilled with pluggers and blasted.

After a cut of ore is taken out, the chutes are built up, the floor is removed, and filling is run in the stope through waste raises from the level above. When the required amount of waste is in the stope the floors are relaid and the place is ready for another cut of ore to be taken.

During the investigation the number of men in the stopes in which the tests were made varied, but generally a drill runner and two shovelers worked in each place. No figures for individual stopes are available.

At the time of the investigation at the United Verde mine about 45 per cent of the underground ore was mined by the horizontal

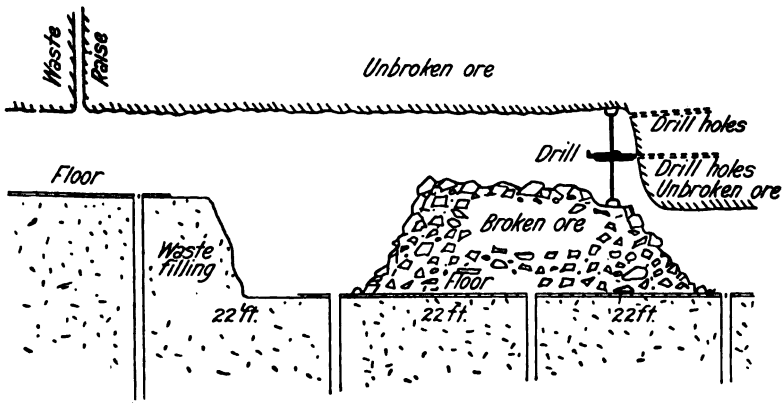

FIGURE 1.—Vertical section of a stope in the United Verde mine

cut-and-fill method. The horizontal cut-and-fill stopes are about 125 feet wide and are carried across the ore body; pillars are left between stopes. The cuts are 7.2 feet high.

Figure 1 shows the method of mining in these stopes. After the ore is broken it is shoveled into chutes 22 feet apart, from which it is drawn into motor-hauled cars on the level below. After the ore from each cut is shoveled into the chutes the floor is removed and the ore chutes built up. A section of filling the same height as the ore cut is then placed in the stope, and the floors are relaid. The filling is drawn from raises into hand-trammed cars and run to the place desired. Bad blocks of ground are held up by cribs built of 10 by 10 inch timber. The system of mining at the United Verde has been described by H. De Witt Smith and W. W. Birdman.[1]

[1] Smith, H. De Witt, and Birdman, W. W., "Mining methods and costs at the United Verde mine": Trans. Am. Inst. Min. and Met. Eng., vol. 66, 1922, pp. 155–164.

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At the United Verde the working force in the stope in which the tests described here were made consisted of 6 drifter-drill runners, 8 jackhammer-drill runners working on bowlders, 11 shovelers, a jigger boss, and carmen and timbermen whose number varied from day to day.

The drill runners and shovelers worked on a bonus system. A standard was set for each class of work and the men received additional compensation for all work more than the standard. For miners the standard per shift was 324 cubic feet of ore in place. For shovelers and pluggers the standard in each stope was fourteen 1-ton cars per man per shift. Two shifts, 8 a. m. to 4 p. m., and 4.30 p. m. to 12.30 a. m., were worked at both mines.

DRILLING PRACTICE

Three types of rock drills—drifters, stopers, and pluggers—were used in the stopes at the Calumet & Arizona mine, depending on the rock and the face. Drifters were used for horizontal holes in vertical faces, pluggers for drilling in pillars and for slabbing rounds, and stopers for drilling vertical holes. Drifter rounds were usually drilled 5 to 8 feet deep, and the holes were generally finished $1\frac{9}{16}$ inches in diameter. Stoper rounds were drilled 3 to 6 feet deep and plugger rounds 2 to 5 feet deep. The stoper and plugger holes were drilled with the same size of steel and were 1¼ inches in diameter at the bottom.

As the drifter machine is used on a column, the opportunity for placing the holes to the best advantage to prevent bowlders is less than with the other types of drills.

Stope rounds at the United Verde mine are drilled horizontally with drifter machines set on bars on vertical columns at the face. The holes of the rounds are generally slightly fan shaped. To drill these rounds with stopers is not practical, as the ground is too hard and for men to drill under the brow is considered a greater hazard. Bowlders are plugged with jackhammers. Hollow round 1¼-inch steel is used for the drifters and ⅞-inch hollow octagon steel for the pluggers. Starter bits for drifter rounds are 1⅞ inches in diameter with a difference of one-sixteenth inch between each succeeding change. For plugging 1¼-inch bits are used. The stope rounds are drilled 5 to 10 feet deep and average about 7.5 feet. Five to nine holes are generally drilled from the same set up.

In blasting stoper rounds, the nearest free face is ordinarily at the collar of the holes, hence breakage is mostly in this direction, whereas with horizontal drifter rounds most of the force is at right angles to the direction of the bore holes. As the end of the explosive charges in stoper rounds comes to the line of break, the back of the stope is often left more shattered than when horizontal holes are used.

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BLASTING PRACTICE

Explosives are taken underground daily at the Calumet & Arizona and three times a week at the United Verde, and are stored in magazines near the main workings on each level. Magazine men give out the explosives and blasting supplies and keep a record of what is used at the various places. The shift bosses check up on the miners' requisitions.

"Powder monkeys" at the Calumet & Arizona visit each of the working places during the latter part of the shift and get the miners' orders for explosives, fuse, and detonators (blasting caps), and then deliver the blasting supplies at the face at loading time. At the United Verde the powder-magazine men do part of this work.

AMOUNT OF EXPLOSIVE USED

Miners are generally allowed to use their judgment as to the amount of explosive needed and their own methods of loading and blasting, provided they obtain satisfactory results. They commonly use one cartridge to the foot of hole in average ground irrespective of the class or grade of explosive. The mine superintendent decides on the kind, class, grade of explosive, and size of the cartridges to be used in any particular place.

In the tests at the Calumet & Arizona mine low-freezing gelatin dynamites of 40, 60, and 80 per cent strength were used. Test rounds at the United Verde were blasted with gelatin dynamites of 35, 50, and 80 per cent strength. Cartridges were 1¼ or 1⅛ inches in diameter by 8 inches long.

TIME FOR BLASTING

At both mines the miners do the blasting. At the Calumet & Arizona blasting is done at the end of each shift; at the United Verde all blasting for both shifts, except of bowlders, is done at the end of the afternoon shift, which allows eight hours for the smoke from the main blasts to clear away before the day shift comes on. Pluggers blast bowlders at the lunch period and at the end of each shift.

FUSE AND DETONATORS USED

All blasting in stopes in regular work at both mines is done by means of fuse and detonators. An excellent grade of fuse is used by both companies. No. 8 detonators are used in stope and drift rounds, and No. 6 detonators are used with the explosive for plugging bowlders at the United Verde. All blasting at the Calumet & Arizona is done with No. 8 detonators.

Fuse for stope rounds is cut in 7-foot lengths at the Calumet & Arizona and in 9-foot lengths at the United Verde. Three-foot

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lengths are used for plugging at both mines. The detonators are crimped on the fuse above ground, and a supply is sent to the magazines on each level as needed. Primers are made by inserting the detonator centrally in the end of a cartridge. When a hole is loaded the primer is placed near the bottom of the charge in the hole with the end holding the detonator downward, and the fuse is brought back along the side of the cartridge. Except for the primer, one slit in the paper is ordinarily made down one side of each cartridge before loading. During the last tests at the United Verde the miners did not slit the cartridges, and placed two at a time in the bore holes and tamped them together. The cartridges of the charges were pressed firmly into place in the bore hole, and, with the exception of the primer, the sticks were also tamped with short, hard blows.

USE OF STEMMING

Stemming was not being used in any part of either mine when the first tests began, but before the work was completed an effort was made to have it used throughout both workings. Stemming, made of sand, in 1¼ by 10 inch cartridges, is now kept in boxes at the underground powder magazines. When stemming was used, two sticks were placed in each bore hole one at a time and firmly tamped in place. Most of the miners here, as elsewhere in metal mines, seemed to have a prejudice against stemming, and close supervision was required to see that it is used in all rounds.

FIRING METHODS

During the investigation the miners loaded and fired the holes in their usual manner. Efforts were made, however, to have all the rounds in each series of tests blasted uniformly.

No comparisons were made between the instantaneous firing of a whole round and the shooting of the holes one at a time. Under some conditions the added jar to the back and the walls of a stope from all of the holes going together would make this practice inadvisable.

A successful method of blasting deep stope holes with divided charges was developed by the investigators during the tests. Instead of putting about 7 cartridges in the bottom 42 inches of a hole, as is usually done, 5 cartridges were loaded in the hole, then 3 or 4 sticks of stemming were tamped in place; next the other 2 cartridges were loaded, and finally the hole was tamped to the collar with stemming.

The proportion of the total explosive contained in the inner and in the outer charges, and the amount of stemming used between the two charges, depended on the relative amount of burden to be broken at the bottom and at the collar of the hole.

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These two charges in the same hole were fired by one of three methods: 1, With cordeau-Bickford detonating fuse; 2, with electric delay detonators; 3, with fuse and detonators.

CORDEAU-BICKFORD

In the first method a length of cordeau-Bickford was placed in the hole before the explosive was loaded. The lower charge was shot in the usual manner with detonator and fuse. This first charge, on exploding, set off the cordeau, which in turn simultaneously detonated the outer charge. The primer containing the detonator was generally placed the second or third cartridge from the bottom, depending upon the length of the fuse and the depth of the hole.

The cordeau-Bickford method proved very efficacious in preventing bowlders, but as the detonating fuse costs about 5½ cents per foot, the use of extra explosives instead of stemming between the two charges in the hole would seem to be cheaper.

The two charges in the same hole could be simultaneously detonated with electric detonators instead of the cordeau. However, no blasting was done with instantaneous electric detonators, as the holes in a round could not be fired in sequence with them.

ELECTRIC DELAY DETONATORS

Some rounds were shot with electric delay detonators at the United Verde, but as "war-time" material was used, many of the holes missed fire and the blasts were failures. The bottom tiers of holes in these rounds were shot with no delay or first delay electric detonators. The other charges of the top holes were shot with second delay and the inner charges with third delay. As all of the detonators of any delay seldom explode together it would not be good practice to shoot the outer and inner charges in a hole with the same delay. In addition to the extra cost of electric delay detonators more time is needed to wire the rounds when this method of blasting is used.

FUSE AND DETONATORS

Two charges in the same hole were blasted separately with fuse and detonator by placing a primer in each charge and firing the outer charge first. The fuse of the bottom charge should be cut so that the train of fire is near the primer at the bottom of the hole when the first charge explodes. With some explosives the outer charge will set the inner one off through three or more sticks of stemming, which is no disadvantage. However, gelatin over 6 months old might not communicate through even one stick of stem-

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ming. Sometimes the first charge detonating may cut out part of the bottom one and mix the explosive with the broken ore.

CAUSES OF BOWLDERS

Bowlders are formed in stopes in hard-ore deposits when the explosive used to break down the ore has not enough shattering power. Bowlders will also be formed if not enough explosive is used or if too much burden is placed on a hole. In softer deposits the ore is generally broken up enough by merely falling from the back to the floor of the stope.

Slips or planes of weakness occur in ore deposits. Ore will occasionally break to a slip and cause bowlders in spite of the kind of explosive used or the method of loading. The first hole of a round may also break out to a slip and bring down the charge in one of the subsequent holes before it has a chance to detonate. The only way to get better results under such a condition is to use more care in placing the bore holes.

Occasionally, observation of the shape of a back in a stope will show that when the round is shot a large part of the ore will come down in big fragments. This condition could often be improved by drilling a short hole at the proper place in the back and shooting it for the first hole of the round. Besides breaking up the projecting part, the shot would afford relief to the other holes of the round. Whether this method would be the most economical would depend on local conditions. In some of the stopes where the tests reported in this paper were made more drill shifts were frequently worked in plugging bowlders than in drilling at the face.

The amount of explosive generally used per hole in stope rounds is not enough to fill more than the bottom part of deep holes, and several feet of the face at the collars may come down without having a chance to be fractured by the explosive. Long holes in hard ore blasted in this manner cause bowlders, no matter what kind of explosive is used. This condition is improved by using divided charges, which gives a better distribution of the force of the explosion. The same result could probably be obtained by using a bore hole of smaller diameter. At many mines, however, including the two where the tests were made, to drill holes of smaller diameter is not practical.

In the stopes in which these tests were made it is customary in stoping with drifting machines to drill two tiers of holes in a vertical face in a back. Most miners drill the lower holes so that the burden on them is greater than on the upper ones. This practice tends to make bowlders. At the United Verde mine the upper holes of the round were generally started about 6 inches from the back of the stope, and the lower tier of holes was drilled 2 to 3 feet

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below the upper ones. In a 7-foot face this practice gives the lower holes about an average of 1 foot more ground to break than the upper ones, where there is no overbreak from the previous round. When there is much overbreak, fewer holes are generally drilled in the lower tier. The working faces are seldom vertical, but slant back at various angles. The overbreak itself is also one of the most fruitful causes of bowlders. Figure 2 shows bowlders due to overbreak to a slip.

PROCEDURE FOR TESTS

Very few conclusive comparative results were obtained by blasting one round with an explosive, or in a certain manner, and then shooting the next one with another explosive, or in a different manner,

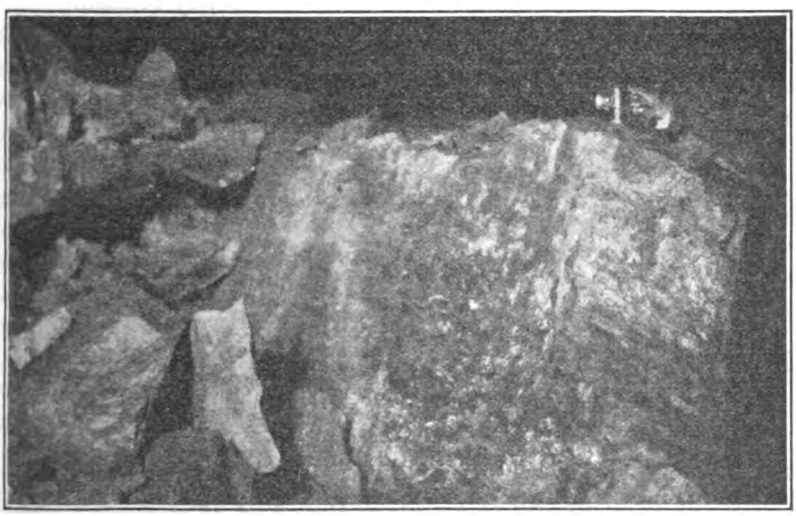

FIGURE 2.—Bowlders due to ore breaking ahead of stope round to a slip, No. 4 stope, 1,650 level, United Verde mine

as it was seldom possible to obtain two successive rounds with the same amount of burden on the individual holes or with the same number of free faces; nor could there be any assurance that the hardness of the rock or the occurrence of slips would be the same. The only alternative, therefore, was to blast enough rounds to obtain average results, and this was done. A total of 61 rounds at the Calumet & Arizona mine and 36 rounds at the United Verde mine was blasted.

Occasionally comparative results were obtained by blasting adjoining rounds with two grades of explosive on one shift and reversing the grade for the next.

An effort was made to have all the holes loaded in a uniform manner and to have the rounds drilled as near alike as possible for each series of tests.

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The rock was classified in each round for hardness ("1" being the hardest) and for slips ("A" being the most conducive for the formation of bowlders). The burden on each hole and the number of free faces, the depth and number of holes, the cartridge size, class, and grade of the explosive used for each round were recorded. The broken material resulting from the blasts was classified as to size, and the proportions over 24 inches in diameter, 8 to 24 inches, 2 to 8 inches, and fines under 2 inches were tabulated. To screen or weigh the ore broken by the blasts was not practicable. The proportion of the different sizes was estimated from experience gained elsewhere. As an aid, the number of the fragments in sight over 24 inches in diameter and from 8 to 24 inches were counted after each blast. Any errors in the estimation should be fairly constant.

The hardness was estimated mainly by the drilling speed while drilling the round. The classification of relative slips was made from observing the face and back, and the general condition of the part of the stope where the round was drilled. The burden on each round was considered only with respect to its being favorable or unfavorable for the formation of bowlders and was recorded as varying from "excellent" to "very poor." The free faces for each round were estimated for all the round and not for individual holes. The free faces for a round with a square face in a stope, as shown in Figure 1, would be two. The free faces in a drift round would be one and in a cubical bowlder six.

At the Calumet & Arizona three series of tests were made, the first August 29 and August 30, the second September 22 to September 27, and the third November 7 to November 22, 1922, to compare the bowlders made by blasting with 40, 60, and 80 per cent strength low-freezing gelatins and to ascertain the effect of stemming. Most of the work was done in two stopes, S–308 on the 1,500 level and No. 4 stope on the 1,700 level. A few rounds were shot in N-308 stope on the 1,500 level.

At the United Verde mine two series of tests were made in the No. 4 stope on the 1,650 level; the first test ran from January 4 to 18, and the second from May 14 to 18, 1923. Fifty per cent strength low-freezing gelatin was used during the first series, and results with and without stemming were noted. The method of loading two charges in long holes was developed, and some comparative results were obtained. The object of the second series was to obtain a comparison of the size and number of bowlders made by 35 and by 80 per cent strength low-freezing gelatin.

The coarseness of the broken ore already in the stope at the United Verde at the beginning of the first series of tests was about the same as at the start of the second series. The regular blasting in this stope before the first tests began was being done with 50 per cent

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strength low-freezing gelatin, without stemming. At the time the second series started the ore was being broken with 35 per cent strength low-freezing gelatin, with stemming. The results obtained at the United Verde corresponded with and confirmed those obtained at the Calumet & Arizona.

TESTS OF HARDNESS AND TOUGHNESS OF ORE

A sample of the ore from the stope in which the work was done at the United Verde was submitted to the Department of Agriculture, Bureau of Public Roads, for testing. The following is the result of the tests of this sample:

Physical properties of ore blasted at United Verde mine

Specific gravity	4.03
Weight per cubic foot, pounds	251
Water absorbed per cubic foot, per cent	0.03
Hardness	19
Toughness	37

The Bureau of Public Roads has tabulated tests of rocks used in road building. The figures published show that diabase was the toughest rock tested and quartzite the hardest. The results of tests of these two rocks and of limestone are as follows:

Toughness and hardness of rocks for road building

Kind of rock	Number of samples	Toughness		Hardness	
		Range	Average	Range	Average
Diabase	29	4 to 54	25	10 to 19	18
Quartzite	61	4 to 30	17	16 to 19	19
Limestone	875	2 to 25	9	2 to 19	14

Different specimens of the same kind of rock differ greatly in hardness and toughness.

It will be noted that the sample from the United Verde is as hard as any of the rocks tested for road building and is tougher than the average of the toughest kind tested. Individual specimens of diabase, however, show greater toughness.

METHOD OF DETERMINING TOUGHNESS

The toughness is determined by the Bureau of Public Roads[2] by subjecting a cylindrical test specimen measuring 25 by 25 mm. (1 by 1 inch) to the impact produced by the fall of a 2-kg. (4.4-pound)

[2] Standard and Tentative Methods of Sampling and Testing Highway Materials, Recommended by the Second Conference of State Highway Testing Engineers and Chemists: U. S. Department of Agriculture Bull. 949, 1922.

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hammer upon a steel plunger resting on the sample. The lower end of the plunger is spherical in shape and has a radius of 1 cm. After the first trial, in which the hammer falls 1 cm., the energy of the blow delivered is increased by increasing the height of fall of the hammer 1 cm. (0.39 inch) after each blow. The height of blow in centimeters at which the failure of the specimen occurs is called the toughness of the specimen.

METHOD OF DETERMINING HARDNESS

Hardness is determined by subjecting both ends of a cylindrical rock core 25 mm. in diameter, drilled from the sample being tested, to the abrasive action of quartz sand fed upon a revolving steel disk.

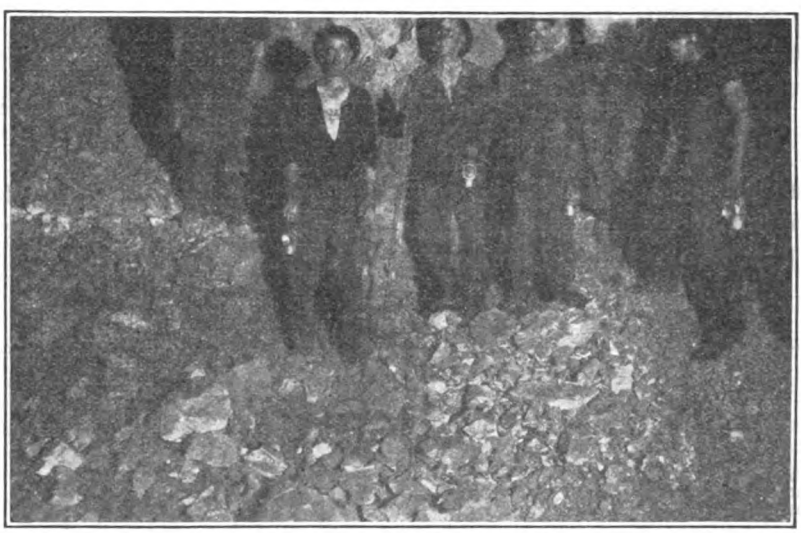

FIGURE 3.—Ore after the blasting of a round in No. 4 stope, Calumet & Arizona mine, with 80 per cent gelatin. Stemming used

Each end of the specimen is worn away in inverse ratio to its hardness, and the amount of loss is expressed in the form of a coefficient of hardness, $20\frac{1}{3}\ w$, where w equals the loss in weight after 1,000 revolutions of the disk. The results obtained on the two ends are averaged and the result is expressed to the nearest whole number.

RESULTS OF BLASTING TESTS

Table 1 shows the average results of the investigations at both mines. Each line of the table gives the average results obtained by blasting a number of rounds on various dates in a particular stope with one grade of explosive, with or without stemming. The first column shows the name of the stope, the second gives the number of

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rounds blasted, the third the total number of holes in these rounds, and the fourth the total footage of holes in each series of tests. The headings of the other columns are self-explanatory.

EFFECT OF HIGH-GRADE GELATIN DYNAMITE

It will be noted from the average results shown in the table that at the Calumet & Arizona the use of gelatin dynamite of 80 per cent strength in place of the 40 per cent in stope S-308 reduced the number of bowlders nearly one-half, and also nearly doubled the amount of fines.

Figure 3 shows a round blasted with gelatin of 80 per cent strength in No. 4 stope. The ore in this stope was harder than in stope 308 and broke larger under similar conditions and with the same explosive.

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TABLE 1.—*Results of blasting tests at the Calumet & Arizona and the United Verde mines*

Place	Number of rounds	Number of holes	Footage of holes	Average depth of holes, feet	Explosive: Cartridges: 8 inch, number	Explosive: Cartridges: Diameter, inches	Explosive: Grade	Explosive: Pounds per foot of hole	Stemming, sticks per hole	Kind of round	Free faces	Burden	Relative slips [1]	Relative hardness [2]	Total broken material: Over 24 inches, per cent	Total broken material: 8 to 24 inches, per cent	Total broken material: 2 to 8 inches, per cent	Total broken material: Under 2 inches, per cent	Total broken material: Bowlders plugged	Remarks
CALUMET & ARIZONA MINE—AVERAGE OF ALL ROUNDS GROUPED																				
N-308	5	41	164	4	244	1	40	0.55	0	Stoper in back	2	Poor−	A	2−	39	18	32	11	16	Rounds not well drilled.
S-308	9	57	256	4½	299	1	40	.45	0	Stoper in side and back	1.7	Good	A−	2−	9	27	48	16	3	Rounds well drilled.
	3	22	85	4	105	1¼	60	.62	0	Stoper in back	2.7	Poor+	A	2−	12	24	47	17	3	Not enough rounds for fair average.
	6	41	149	3½	152	1	80	.36	0	Stoper in back and face	1.8	Fair+	B+	1+	5	14	54	27	2	
	2	14	97	7	105	1¼	60	.55	0	Drifter and stoper in face	1.8	...do	A−	2−	15	47	21	17	11	Do.
	3	34	185	5½	175	1¼	60	.46	2	Drifter in face and stoper in back.	1.8	Good+	A−	1	8	25	47	20	10	Do.
	8	41	189	4½	203	1¼	80	.42	0	....do	2	Fair−	A−	2	9	33	43	15	7	Average conditions.
	12	69	310	4½	208	1¼	80	.47	1 2	Stoper in side and back	1.7	...do	A−	1+	4	9	60	27	2	Do.
UNITED VERDE MINE—AVERAGE OF ALL ROUNDS GROUPED																				
No. 4	6	75	434	6		1¼	50	.57	0	Drifter in stope breast	2	Fair	B+	2−	42	27	27	4		Average conditions.
	7	72	427	6	435	1¼	50	.55	2	....do	2	...do	A−	2−	23	24	45	8		Do.
	6	52	305	6	319	1¼	50	.59	3	....do	2	...do	A−	2	16	19	52	13		Average conditions; separated charges.
	3	22	162	7½	175	1¼	35	[3].52	2	....do	2	...do	B	2	37	32	29	2		Average conditions.
	10	72	519	7	565	1¼	80	[4].48	2	....do	2	...do	B	2	18	26	45	11		Do.

[1] "A", most conducive to making bowlders.
[2] "1", hardest.
[3] 210 tons were broken at a cost of 0.48 pound of explosive per ton.
[4] 799 tons were broken at a cost of 0.32 pound of explosive per ton.

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EFFECT OF STEMMING

In stope No. 4 of the Calumet & Arizona mine the use of stemming with gelatin dynamite of 60 per cent strength reduced the bowlders nearly one-half, although the amount of fines remained about the same. The use of stemming with gelatin dynamite of 80 per cent strength in stope No. 4 reduced the large bowlders by one-half and

FIGURE 4.—Ore after the blasting of a round in stope N-308, Calumet & Arizona mine, with 40 per cent gelatin. No stemming used

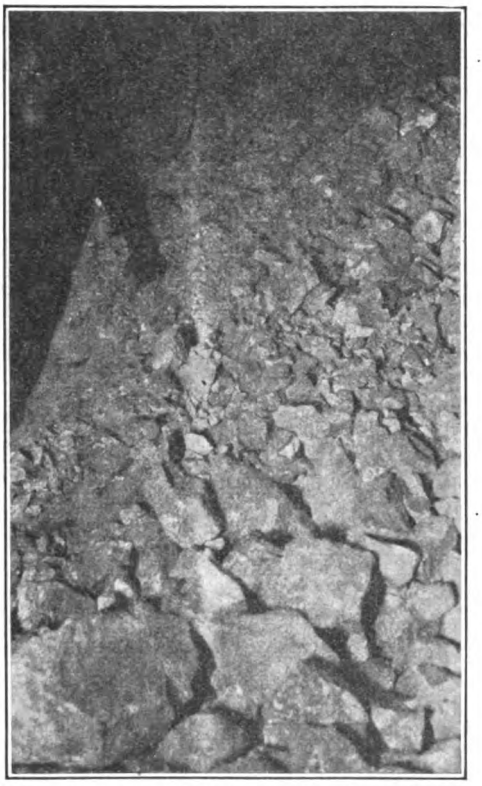

FIGURE 5.—Ore after the blasting of a round in stope N-308, Calumet & Arizona mine, with 40 per cent gelatin. Stemming used

those 8 inches thick by two-thirds, and increased the amount of fines. The table shows that gelatin dynamite of 60 per cent strength with stemming is about equal to the 80 per cent without stemming.

Figure 4 shows the ore after a round in stope N-308 with 40 per cent strength gelatin and no stemming.

Figure 5 shows results of a similar round in the same stope with the same explosive, but with stemming used. Note the smaller size of the bowlders.

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Figure 6 shows how the ore in the same stope was broken by a round charged with 80 per cent gelatin. Figures 3 and 6 show the ore broken to a size that can be easily handled.

In the tests at the United Verde the percentage of bowlders over 8 inches in diameter resulting from the use of explosive of 35 per cent strength, with stemming, and the percentage produced with 50 per cent strength, without stemming, constituted about 70 per cent of the total material broken in each test. The bore holes in the rounds in which the 35 per cent strength was used were longer, a fact that probably had some unfavorable influence. The use of stemming with the 50 per cent strength explosive reduced the propor-

FIGURE 6.—Broken ore after the blasting of a round in stope S-308, Calumet & Arizona mine with 80 per cent gelatin. No stemming used

tion of bowlders over 8 inches in diameter from 69 per cent to 47 per cent of the whole amount broken.

The substitution of gelatin of 80 per cent strength for 35 per cent reduced the average percentage of bowlders over 8 inches from 69 to 44 and increased the proportion of fine ore fivefold. The average results obtained by using the 80 per cent with stemming were about the same as those obtained by using separated charges of the 50 per cent strength with stemming. The bore holes of the rounds in which the 80 per cent was used were longer on an average than those in which the 50 per cent was used. The percentage of fine material resulting from the use of the higher grades of explosives was considerably larger.

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EFFECT OF DIVIDED CHARGES

By dividing the charges in the long holes that had an equal burden to break for their entire length the proportion of bowlders was reduced to 35 per cent of the total material broken, or one-half of the proportion made by the same explosive when shot in a single charge with no stemming.

FIGURE 7.—Broken ore from the blasting of stope round, No. 4 stope, 1,650 level, United Verde mine, with 50 per cent gelatin. No stemming used

FIGURE 8.—Broken ore in adjoining round, same face as Figure 7, from blasting with 50 per cent gelatin. Divided charges and stemming used. Note smaller proportion of bowlders

Figures 7 and 8 show two adjacent rounds, one shot with gelatin of 50 per cent and no stemming, and the other with the same explosive in separated charges.

Occasional contiguous or subsequent rounds that were blasted with different explosives or by different methods gave direct comparative results that are of interest. Two subsequent rounds blasted in No. 4 stope of the United Verde mine under similar conditions, one with gelatin dynamite of 80 per cent strength and the other with 35 per cent strength, both with stemming, showed that the material over 8 inches from the former round was 45 per cent, whereas from the lat-

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ter round it was 65 per cent. Two pairs of adjacent stemmed rounds blasted with these two explosives averaged 48 per cent of material over 8 inches in diameter when shot with gelatin of 80 per cent strength and 70 per cent when shot with gelatin of 35 per cent strength.

AMOUNT OF FINES MADE

A saving of labor was made in each of the previously described rounds where gelatin of 80 per cent strength was used, as a man with a jackhammer took one shift longer to plug the bowlders from the blasts with the 35 per cent gelatin than to plug those from the stronger explosive.

The larger proportion of fines made with the higher-grade explosives is an advantage because less crushing is required at the smelter to prepare the ore for the roasters. Although this saving would not be reflected in the mine figures, the total cost of producing the copper is reduced. J. B. Johnson [3] points out that the crushing of the United Verde ore is an extremely difficult problem, especially as the ore must be crushed to one-quarter inch size before roasting.

PRACTICAL RESULTS FROM THE TESTS

These methods of blasting and these grades of explosives that gave the best results in the tests at the Calumet & Arizona mine have been continued in use in the hard-ore stopes. Two years after the tests were made Fred Santher, foreman of the mine, said that—

> Each time, when for any reason a lower grade of explosive is used, or no stemming is available, an increase in the number of bowlders which require secondary breaking is immediately evident in these stopes.

Although figures for individual stopes are not available, Mr. Santher thinks that the use of higher-grade explosives and stemming has decreased appreciably the cost per ton of mining in the hard-ore stopes.

After a long series of tests the present drilling practice in the cut-and-fill stopes at the United Verde was adopted as being the most economical. In stope No. 4, where the bowlder tests were made, the costs in November, 1922, for 9,000 tons of ore were as follows:

Drilling and blasting costs per ton, United Verde mine

Mining (drill runners)	$0.12
Pluggers (drill runners)	.08
Explosive for mining	.06
Explosive for plugging	.05
Shovelers and carmen	.23
Timbering and timber	.24
Total	.78

[3] Johnson, J. B., "The United Verde crushing plant": Arizona Min. Jour., vol. 7, Dec. 15, 1923, pp. 5–6.

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This cost does not include compressed air, supplies, bosses, or any overhead. It will be noted that to plug and blast bowlders costs more than two-thirds as much as to break the ore from the back.

In 1918 the average cost of mining in the cut-and-fill stopes[4] was $0.210 per ton for mining (drill runners) and $0.082 per ton for pluggers. Three and sometimes four rows of holes were drilled in the breasts in the hard-ore stopes at the time these former costs were obtained and apparently, under the conditions existing at this place, to blast down the ore to slips or otherwise with as few holes as possible and then break up the large fragments later is more economical. All the reduction in cost of drilling the primary rounds can not be attributed to the change in drilling practice, as in 1918 wages were $5.46 per day for miners, and in 1922, $4.95. Also the bonus system in effect in the stopes in 1922 reduced the amount paid drill runners per ton relatively more than the amount paid pluggers. Pluggers received a bonus with the muckers on the amount of ore shoveled in the stope and were not figured on a separate basis. With the same drilling practice a further reduction in cost apparently could be obtained if the size and amount of bowlders could be reduced.

According to Smith, various mechanical loaders and scrapers have been tried, but because of the bowlders none has proved successful. If the ore could be broken by primary blasting into such small fragments that scrapers could be used, a further saving could be made as fewer ore chutes would be needed.

Probably better results were obtained in the tests than can be expected in ordinary mining, as the presence of investigators may have stimulated the miners to try to drill the rounds more nearly to the standard and to avoid carelessness in loading.

PHYSICAL TESTS OF EXPLOSIVES USED

Samples of the explosives used in these experiments were tested at the explosives experiment station of the Bureau of Mines at Bruceton, Pa. Table 2 gives the results of these tests.

PHYSICAL EXAMINATION

The dimensions given are the averages obtained of four cartridges selected at random from the lot tested, and are correct to within one-sixteenth inch for the diameter and one-eighth inch for the length.

[4] Smith, H. De Witt, Sirdevan, E. M. and W. H., and Jerome, E. M., "Mining methods and costs at the United Verde mine": Trans. Am. Inst. Min. and Met. Eng., vol. 66, 1929, p. 160.

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TABLE 2.—*Comparison of physical tests of gelatin dynamites of 35, 40, 50, 60, and 80 per cent strength*

Percentage strength of explosive	35 L. F.	40	40	50 L. F.	60	80	80
Key number	D-3273	D-3153	D-3151	D-3189	D-3152	D-3155	D-3156
Physical examinations:							
Diameter of cartridges, inches	1⅛	1	1¼	1⅛	1¼	1	1¼
Length of cartridge, inches	8	8	8	8	8	8	8
Average weight, grams	228	166	244	211	251	158	266
Apparent specific gravity	1.65	1.54	1.52	1.58	1.52	1.46	1.40
Weight of wrappers, per 100 grams of explosive, grams	5.0	5.5	4.5	4.5	4.0	5.0	4.0
Gaseous products of explosion in Bichel gauge:							
Weight of gases from 200 grams of explosive plus proportional amount of wrappers, grams	92.1			99.7			
Volume of gases from 200 grams of explosive and proportional weight of wrapper at 0° C. and 760 mm. mercury, liters	125.0			139.0			
Volume of poisonous gases from 454 grams (1 pound) of explosive and wrapper, liters	5.6	[1] 29.3	[1] 24.4	8.5	8.7	36.8	43.6
Composition of gases of explosion, 454 grams explosive and wrapper, per cent by volume—							
Carbon dioxide, CO_2	50.4	37.2	41.3	49.0	54.3	42.2	40.8
Oxygen, O_2	0	0	0	0	0	0	0
Carbon monoxide, CO	4.5	17.2	13.6	6.1	5.4	18.5	19.9
Hydrogen, H_2	1.9	11.8	9.6	4.2	2.7	10.8	10.9
Methane, CH_4	0.2	0	0.9	0.1	0	0	0
Nitrogen (by difference), N_2	43.0	32.6	33.3	40.6	37.5	28.5	28.4
Hydrogen sulphide, H_2S	0	1.2	1.3	0	0.1		
Total	100	100	100	100	100	100	100
Ratio, CO_2 to CO	100:8.9	[1] 100:46.2	[1] 100:32.9	100:12.4	100:9.9	100:43.8	100:48.7
Rate of detonation, meters per second	1,709	2,271 1,661	1,365 1,733	6,142	6,124	6,692	6,006
Age of explosive when tested, months	3	[2]	[2]	3	[2]	[2]	[2]
Unit deflective charge, grams	254	225	232	224	206	186	179
Age of explosive when tested, months	1	[2]	[2]	3	[2]	[2]	[2]
Sensitiveness to detonation, halved cartridge method:							
Minimum distance at which no explosion occurs, 4 trials, inches	0			15			
Maximum distance at which 4 explosions occur out of 4 trials				8			
Age of explosive when tested, months	3			4			
Pendulum friction test:							
Steel shoe	Failed.	Failed.	Failed.	Failed.	Failed.	Failed.	Failed.
Fiber shoe, 10 trials	Passed.	Passed.	Passed.	Passed.	Passed.	Passed.	Passed.

[1] Formula now changed, 17.2 liters of poisonous gases from 1 pound of same grade gelatin, made by the same manufacturers on Apr. 2, 1923.
[2] Date report of tests, Feb. 2, 1923.

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GASEOUS PRODUCTS OF EXPLOSION

Two hundred grams of the explosive, plus its proportion of the original wrapper on the cartridge, was fired in an evacuated 15-liter steel bomb. The volume of gas and poisonous gas was computed for the observed pressure and temperature after cooling. Gases were collected and analyzed. The results are comparative and not absolute, as the method of detonation and the effectiveness of the confinement affect the composition and the volume of the gaseous products. In practice, the degree of confinement for any given shot can only be roughly approximated and the results may vary widely from those shown by the bomb.

RATE OF DETONATION

The time of detonation of a 1-meter length of the explosive of the stated diameter of cartridge is determined by the Mettegang recorder. The ends of the cartridges are cut off square and the cartridges are placed end to end in a galvanized-iron tube or wrapped in heavy manila paper.

As the tests show, the gelatins of 50 and 80 per cent strength are much faster than the 35 per cent strength and should have greater shattering effect. This was demonstrated by the blasting tests.

Some gelatins have two distinct rates of detonation, and the one shown for the 35 per cent is probably the low rate. Gelatin dynamite often becomes insensitive with age, but apparently the 35 per cent gelatin in the lot tested is too insensitive, considering the interval of about three months since its manufacture. A probable explanation of the insensitiveness of this gelatin is discussed under the heading "Sensitiveness to detonation." The 40 per cent low-freezing gelatin tested by Howell and Crawshaw [5] to determine the effect of cartridge diameter on the strength and sensitiveness of certain high explosives had high rates of detonation ranging from 4,800 to 5,200 meters per second, and low rate from 1,800 to 2,500 meters per second.

UNIT DEFLECTIVE CHARGE

The unit deflective charge is that weight of the sample of explosive which is equivalent in deflective strength to 227 grams (one-half pound) of the Pittsburgh experiment station standard 40 per cent "straight" nitroglycerin dynamite. Note that the stronger the explosive the less is its unit deflective charge. According to the table, this particular gelatin of 80 per cent strength

[5] Howell, S. P., and Crawshaw, J. E., Effect of Cartridge Diameter on the Strength and Sensitiveness of Certain High Explosives: Reports of Investigations, Serial 2436, Bureau of Mines, 1923.

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has 27 per cent more propulsive energy than 40 per cent straight dynamite. The gelatin of 50 per cent strength has about the same propulsive energy as the 40 per cent straight dynamite, and the 35 per cent gelatin has 12 per cent less energy. The gelatin of 80 per cent strength has nearly 42 per cent more energy than that of 35 per cent strength. These tests indicate that the 80 per cent gelatin has considerably more explosive power than the 50 per cent or 35 per cent gelatins and, other things being equal, would have a tendency to do more work in the blast and to break the rock in smaller fragments.

SENSITIVENESS TO DETONATION

In testing sensitiveness to detonation the cartridges are cut in two equal parts 4 inches long and rolled in paper tubes at measured distances apart. One-half of the cartridge is detonated by a No. 6 detonator; the distance at which the other half will be exploded by the first is a measure of the sensitiveness by influence of the explosive. In all these tests the half of the cartridge with the detonator exploded.

PENDULUM FRICTION TEST

The pendulum friction test is an indication of the safety of the explosives during loading and handling. Apparently no material difference exists in the results of the pendulum friction tests of the seven samples; all seven passed the friction tests which are required of coal-mine explosives before they are classed as "permissible."

Any two lots of explosives may vary even when made by the same manufacturer, but the general results of blasting with each grade should be fairly constant. The sample of 80 per cent gelatin was taken from the first lot of this grade made by the manufacturer. Later shipments of 80 per cent gelatin may be superior to this lot, as the powder company would have had an opportunity to improve on the technique of manufacture.

CONCLUSIONS

If more consideration is given to the primary blasting in many hard-ore stopes, fewer large fragments will be formed.

Crushing rock by means of explosive is usually more economical than breaking it by hand. Therefore, where bowlders are being formed, more explosive should be used in the drill holes while the extra amount does useful work. In other words, if the walls and back of the stope will withstand the extra jar, an additional cartridge or two in a hole may often be used to advantage.

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The results given in this paper indicate that the use of stemming decidedly helps to prevent formation of bowlders, does not increase the cost of blasting perceptibly, and lessens appreciably the amount of work needed to break up the bowlders. The tests show that one stick of stemming to a hole is not enough and that at least two should be used.

The use of high-grade gelatin dynamites makes a substantial reduction both in the size and proportion of bowlders formed, and also increases the fines in hard-ore stopes. In addition to their greater shattering power, the higher-grade explosives have more propulsive energy per pound, and probably that also contributes to the improved results. Even with the present difference in price, the tests show that the higher grades of explosive are more economical to use.

According to the pendulum friction tests made, the 80 per cent gelatin should offer no greater risk in loading than the 35 or 50 per cent strength. However, since all explosives, because of their nature, may be made to explode by a variety of causes, these gelatin dynamites should be handled with care and caution.

The analyses of the gases from the explosives shown in Table 2 indicate that a relatively large amount of carbon monoxide is made by the 80 per cent gelatin, and unless the formula of this explosive has been changed since the samples were taken its use would seem desirable only where the ventilation is good.

Two charges, separated by stemming, in a long hole having an equal burden for the full length make fewer bowlders than a single charge at the bottom of the hole. Other factors, however, may make this system of blasting uneconomical.

The condition of the back and face was noted after each test round. The amount of trimming and barring down varied greatly, but apparently a slight advantage resulted from the use of the 80 per cent strength gelatin instead of the 40 or 35 per cent. In the opinion of the miners in the stopes where the tests were made at the Calumet & Arizona mine, the rock broke from the back cleaner with the higher explosive, and less trimming was needed.

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